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सौर तापन – पानी गरम करने का घरेलू तंत्र

भाग 1 अंतरंग परीक्षण पद्धतियों द्वारा कार्यकारिता रेटिंग कार्यविधि

Indian Standard

SOLAR HEATING — DOMESTIC WATER HEATING SYSTEMS

PART 1 PERFORMANCE RATING PROCEDURE USING INDOOR TEST METHODS

UDC 683-97 : 697·329 : 620·16

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BUREAU OF INDIAN STANDARDS
MANAK BHAVAN, 9 BAHADUR SHAH ZAFAR MARG
NEW DELHI 110002

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Non-Conventional Energy Sources Sectional Committee, HMD 4

FOREWORD

This Indian Standard (Part 1) was adopted by the Bureau of Indian Standards, after the draft finalized by the Non-Conventional Energy Sources Sectional Committee had been approved by the Heavy Mechanical Engineering Division Council.

A wide variety of solar domestic hot water (SDHW) systems are marketed throughout the world. A natural consequence of this highly dispersed activity is the need to understand, predict and compare the performance of these systems. Standardized test methods are essential for assessing the performance potential. This standard has been developed to help facilitate comparison of these systems.

Because various testing methodologies for determining thermal performance are at different stages of development and acceptance, it has been decided to concurrently prepare separate parts of this standard each covering a separate methodology. The advantage of this format is that each part can proceed on its own and not be delayed until all methodologies are at the same point of development.

This standard is, therefore, being published in following parts:

Part 1 Performance rating procedure using indoor test methods

Part 2 Procedure for system performance characterization and yearly performance predication

Part 3 Procedures for system component characterization and predication for yearly performance using component performance data

Part 4 Test methods to determine durability and reliability.

For the purpose of deciding whether a particular requirement of this standard is complied with, the final value, observed or calculated, expressing the result of a test or analysis, shall be rounded off in accordance with IS 2 : 1960 'Rules for rounding off numerical values (*revised*)'.

This standard applies to solar domestic water heating systems designed to heat water to be supplied for domestic water usage:

a) This standard not intended for other than solar water heating systems designed solely for domestic water usage.

b) The test procedures in this part are applicable to systems of 0·2 m^3 of solar storage capacity or less.

c) This standard includes procedures for testing solar domestic hot water system either with solar irradiance simulators or thermal simulation (non-irradiated) methods.

d) The test procedures in this standard employing a non-irradiated solar collector array in series with a conventional heat source do not apply to an integral collector storage system, a system in which thermosiphon flow occurs or to any system employing a collector/heating transfer fluid combination which cannot be tested in accordance with the collector test.

e) The test procedures in this standard do not require the solar water heating system to be subjected to freezing conditions. Consequently, the energy consumed or lost by a system while operating in the freeze protection mode will not be determined.

f) If a solar system is designed to be used with non-freezing (anti-freezing inhibitors) fluids, the test procedures in this standard must use these fluids according to the manufacturer's requirements.

Indian Standard

SOLAR HEATING – DOMESTIC WATER HEATING SYSTEMS

PART 1 PERFORMANCE RATING PROCEDURE USING INDOOR TEST METHODS

1 SCOPE

1.1 This standard specifies a uniform indoor method of testing for rating solar domestic water heating systems for thermal performance, under benchmark conditions. For the determination of yearly thermal performance, refer to Parts 2 and 3.

1.2 This standard is not intended to be used for testing the individual components of the system.

1.3 This standard is not intended to abridge any safety or health requirements.

1.4 This standard is not generally applicable to concentrating or evacuated tube systems, unless the requirements of **8.8.3** can be met.

2 REFERENCES

The following Indian Standards are necessary adjuncts to this standard:

IS No.	*Title*
12933 (Part 1) : 1991	Solar flat plate collector : Part 1 General requirements
12933 (Part 2) : 1991	Solar flat plate collector : Part 2 Components
12933 (Part 3) : 1991	Solar flat plate collector : Part 3 Measuring instruments
12933 (Part 4) : 1991	Solar flat plate collector : Part 4 Performance requirements and accepted criteria
12933 (Part 5) : 1991	Solar flat plate collector : Part 5 Test methods
12934 : 1991	Solar energy – Thermal applications – Vocabulary

3 DEFINITIONS

For the purpose of this standard, the following definitions shall apply.

3.1 Absorber

Device within a collector for absorbing radiant energy and transferring this energy as heat into a fluid.

3.2 Accuracy

The ability of an instrument to indicate the true value of the measured physical quantity.

3.3 Ambient Air

Air in the space (either indoors or outdoors) surrounding the thermal energy storage device or solar collectors, whichever is applicable.

3.4 Angle of Incidence (of Direct Solar Radiation)

The angle between the solar radiation beam and the outward drawn normal from the plane considered.

3.5 Aperture Area

The maximum projected area of a solar thermal collector through which the unconcentrated solar radiation is admitted.

NOTE – For concentrating collectors, the gross aperture area includes any area of the reflector or refractor shaded by the receiver and its supports and including gaps between reflector segments within a collector module. Net aperture area excludes any shaded area or gaps between reflector segments and is sometimes called effective aperture area.

3.6 Aperture Plane

The plane at or above the solar collector through which the unconcentrated solar radiation is admitted.

3.7 Area, Gross Collector

The maximum projected area of a completed solar collector module, exclusive of integral means of mounting and connecting fluid conduits. For an array of collectors, including devices such as evacuated tube or concentrating collectors, gross area includes the entire area of the array.

3.8 Auxiliary Energy, *See* 3.9.

3.9 Auxiliary Thermal (Heat) Source

A source of thermal energy, other than solar, used to supplement the output provided by the solar energy system; usually in the form of electrical resistance heat.

3.10 Collector, Concentrating

A solar collector that uses reflectors, lenses or other optical elements to redirect and concentrate the solar radiation passing through the aperture on to an absorber of which the surface area may be smaller than the aperture area.

3.11 Collector, Flat-Plate

A non-concentrating solar collector in which the absorbing surface is essentially planar.

3.12 Collector Loop Heater

A heater installed within the collector loop when testing the solar domestic water heating system with a non-irradiated array.

3.13 Collector

A device containing an absorber.

3.14 Collector Tilt Angle

The lower angle between the aperture plane of a solar collector and the horizontal plane.

3.15 Components

Parts of the solar hot water system including but not limited to collectors, storage, pumps, heat exchanger, controls, etc.

3.16 Control

Any device for regulation of the solar thermal system or component in normal operation, can be manual or automatic.

3.17 Direct Irradiance

Irradiance produced by direct radiation on a given plane.

3.18 Direct Solar Radiation

Radiation received from a small solid angle centered on the sun's disk, on a given plane.

NOTE — In general the direct solar radiation is measured by instruments with field of view angles of up to 15°. Therefore a part of the scattered radiation around the sun's disk (circumsolar radiation) is included. More than 99 percent of the direct solar radiation on the earth's surface is contained within the wavelength from 0.3 μm to 3.0 μm.

3.19 Domestic

Refers to use in residential and small commercial buildings.

3.20 Draw Rate

See water draw rate.

3.21 Equivalent Length

The length of a straight section of pipe or duct causing the same pressure drop as actually occurs within the system at the same flow rate.

3.22 Fluid Transport

The transfer of air, water, or other fluid between components.

3.23 Heat Exchanger

A device specifically designed to transfer heat between two physically separated fluids. Heat exchangers can have either single or double walls.

3.24 Heat Transfer Fluid

A fluid that is used to transfer thermal energy between components in a system.

3.25 Incident Angle, *See* 3.26.

3.26 Irradiance

Power density of radiation incident on a surface, that is the quotient of the radiant flux incident on the surface and the area of that surface, or the rate at which radiant energy is incident on a surface, per unit area of that surface (Note : solar irradiance is often termed "incident solar radiation intensity", "instantaneous insolation", or "incident radiant flux density" — the use of these terms is deprecated).

3.27 Load

The daily system hot water load defined as the product of the mass, specific heat, and temperature increase of the water as it passes through the solar hot water system.

3.28 Potable

Means suitable for human consumption.

3.29 Precision

The measure of the closeness of agreement among repeated measurements of the same physical quantity.

3.30 Preheating

See solar preheat system (Definition in Classification of DHW Systems).

3.31 Pyranometer

Radiometer for measuring the irradiance on a plane receiver surface which results from the radiant fluxes incident from the hemisphere above within the wavelength range 0.3 μm and 3 μm.

NOTE — The given spectral range represents roughly the spectral range of solar radiation (also called solar or short wave range) at the ground and is only nominal. Depending on the material used for the domes which protect the receiver surface of a pyranometer the spectral limits of its responsivity meet more or less accurately the above mentioned limits.

3.32 Pyrgeometer

An instrument for determining the irradiance on a plane receiving surface which results from the radiant fluxes incident from the hemisphere above within about the wavelength range 4 μm to 50 μm.

NOTE — The given spectral range is nearly identical with those of the so-called terrestrial radiation or longwave radiation and is only nominal. Depending on the material used for the domes which protect the receiving surface of a pyrgeometer the spectral limits of its reponsivity meet more or less accurately the above mentioned limits.

3.33 Pyrheliometer

A radiometer for measuring direct (solar) irradiance which results from the radiant fluxes incident from a well-defined solid angle whose axis is perpendicular to the plane receiver surface.

NOTE — According to this definition pyrheliometers are applied to measure direct solar irradiance at normal incidence. The field-of-view-angle of pyrheliometers range typically from 5°C to 10°C.

3.34 Solar Collector

See solar thermal collector.

3.35 Solar Thermal Collector

A device designed to absorb solar radiation and to transfer the thermal energy so gained to a fluid passing through it.

3.36 Solar Energy

The energy emitted by the sun in the form of electromagnetic radiation (primarily in the wavelength range of 0.3 μm to 3 μm) or any energy made available by the reception and conversion of solar radiation.

3.37 Solar Contribution

The ratio of energy supplied by the solar part of a system to the total load.

3.38 Solar Noon

For any given location solar noon is the local time of day when the sun is at its highest altitude for that day, that is the time when the sun crosses the observer's meridian.

3.39 Solar Radiation

The radiation emitted by the sun. Practically all of the solar radiation incident at the earth's surface is at wavelengths between 0.3 μm to 3 μm and is often termed "short wave radiation".

3.40 Solar Irradiance Simulator

An artificial source of radiant energy simulating the solar radiation, usually an electric lamp or an array of such lamps and associated assembly.

3.41 Solar Storage Capacity

The quantity of sensible heat that can be stored per unit volume of store for every degree of temperature change.

3.42 Solar Hot Water System

The complete assembly of subsystems and components necessary to convert solar energy into thermal energy for the heating of water. It may include an auxiliary heat source.

3.43 Standard Air

Air weighing 1.204 kg/m³ which approximates dry air at a temperature of 150°C and a barometric pressure of 101.325 kPa.

3.44 Standard Barometric Pressure

The barometric pressure of 101.325 kPa at 0°C.

3.45 Storage Device (Thermal)

The container(s) plus all contents of the container(s) used for storing thermal energy. Note : The transfer fluid and accessories such as heat exchangers, flow switching devices, valves, and baffles which are firmly fixed to the thermal storage container(s) are considered a part of the storage device.

3.46 Storage Tank Volumetric Capacity

The measured volume of the fluid in the tank when full.

3.47 Temperature, Ambient Air

The temperature of the air surrounding the thermal energy storage device or solar collectors being tested. Note : Significant differences can occur over short distances, therefore, in particular applications, the method of measurement must be specified.

3.48 Time Constant

The time required for a first order system to have its output change by 63.2 percent of its final change in output following a step change in its input.

3.49 Thermopile

A number of thermocouples wired consistently in series or parallel to measure small or average temperature differences.

3.50 Water Draw Rate

The rate at which the hot water is withdrawn from the system at a specified time during the day.

4 SYMBOLS AND ABBREVIATIONS

Symbol — *Meaning*

A_a = collector module aperture area, m²

$\frac{A_a F_R (\tau\alpha)_{e,n}}{A_g}$ = intercept of the collector efficiency curve determined in accordance with collector tests, dimensionless

$\frac{A_a F_R U_L}{A_g}$ = slope of the collector efficiency curve determined in accordance with collector tests, kJ/(h.m².°C)

A_g = gross collector area, m²

$C_{p,c}$ = specific heat of the transfer fluid used in the collector during the collector tests, kJ/(kg.°C)

$c_{p,s}$ = specific heat of the transfer fluid used in the collector during the solar hot water system test, kJ/(kg. °C)

$c_{p,w}$ = specific heat of water, kJ/ (kg. °C)

D = nozzle throat diameter, m

F = collector absorber plate efficiency factor, dimensionless

F_R = collector heat removal factor, dimensionless

Symbol	*Meaning*
G_{bp}	= beam irradiance from solar irradiance measured in a plane parallel to the collector aperture, kJ/(m^2.h)
G_d	= diffuse irradiance from solar irradiance measured in a plane parallel to the collector aperture, kJ/(m^2.h)
G_t	= total (global) irradiance incident upon the aperture plane of the collector, kJ/(m^2.h)
$K_{\alpha\tau}$	= incident angle modifier, dimensionless
M	= number of rows of collector modules in parallel in the collector array, dimensionless
m_c	= mass flow rate of the transfer fluid through the collector during the collector tests, kg/s.
m_j	= the mass of the jth withdrawal of water, kg
m_s	= mass flow rate of the transfer fluid through the collector array during the solar hot water system test, kg/s
N	= number of collector modules in series in each parallel row in the collector array, dimensionless
NS	= subscript to denote solar energy input
Q_{AUX}	= daily energy consumed for auxiliary heating in the solar hot water system, kJ
$Q_{L, NS}$	= daily system hot water load defined as the product of the mass, specific heat, and temperature increase of the water as it passes through the solar hot water system for the case of no solar energy input, kJ
Q_{LOS}	= thermal losses from solar system during the test day, kJ
$Q_{L,S}$	= daily system hot water load defined as the product of the mass, specific heat, and temperature increase of the water as it passes through the solar hot water system for the case of solar energy input, kJ
$\dot{Q}_{th}$	= rate of energy output from the collector loop heater in series with the non-irradiated solar collector array (if used), kJ/h
Q_{PAR}	= daily energy consumed for parasitic power by pumps, controls, solenoid valves, etc, in the solar hot water system, kJ
Q_{OUTPUT}	= energy output from the collector loop heater (if used) during the test, kJ
Q_S	= daily net energy output from the solar collector and solar storage parts of the solar hot water system, kJ
$\dot{Q}_u$	= rate of useful heat output from the collector, kJ/h
R	= rating number which is the ratio of the auxiliary plus parasitic energy to the daily system load during the solar day $[(Q_{AUX} + Q_{PAR})/Q_L]$, dimensionless
S	= subscript to denote case for solar energy input
sf	= fraction of hot water load supplied by solar energy, dimensionless
t_a	= ambient air temperature, ^{0}C
$t_{a, l}$	= ambient air temperature in the laboratory during the system test, ^{0}C
$t_{a, t}$	= ambient air temperature specified for the test solar day, ^{0}C
$t_{f, i}$	= temperature of the transfer fluid entering the collector, ^{0}C
$t_{f, e}$	= temperature of the transfer fluid leaving the collector, ^{0}C
t_i	= mixed temperature of the water withdrawn from the solar hot water system, ^{0}C
$t_{p, m}$	= mean plate temperature of the collector absorber, ^{0}C
$t_{p, m, non}$	= mean plate temperature of the collector absorber under non-irradiated conditions, ^{0}C
t_{set}	= ultimate desired hot water delivery temperature after the addition of supplemental energy, ^{0}C
$t_{w, j}$	= mixed temperature of the jth withdrawal of water to the load, ^{0}C
$t_{s, j}$	= mixed temperature of the jth withdrawal of water from solar tank, ^{0}C
t_{main}	= temperature of the incoming cold water supply to the solar hot water system, ^{0}C
U_L	= collector heat transfer loss coefficient, kJ/(h.m^2. ^{0}C)
V	= total volume draw as determined from no solar input test
d_n	= absorptance of the collector absorber coating to the solar spectrum at normal incidence, dimensionless
θ	= angle of incidence between the direct solar beam and the normal to the collector aperature, deg

Symbol		*Meaning*
θ_m	=	angle of incidence between the beam irradiance from solar irradiance simulator and the normal to the collector aperture deg
ρ_d	=	specular reflectance of the cover plate assembly at an incident angle of 60°, dimensionless
τ_n	=	transmittance of the cover plate assembly to the solar spectrum at normal incidence, dimensionless
$(\tau\alpha)_{c,n}$	=	effective transmittance – absorptance product for the collector at normal incidence, dimensionless
$\sum\limits_{j=1}^{n}$	=	represents a summation over all water withdrawal periods during a test day

5 CLASSIFICATIONS

Solar domestic hot water systems are classified by seven attributes, each distinguishing two or three categories, as shown below :

System Descriptors

	a	b	c
5.1	Solar only	Solar pre-heat	Solar plus supplementary
5.2	Direct	Indirect	
5.3	Open	Vented	Closed
5.4	Filled	Drainback	Draindown
5.5	Thermosiphon	Forced	
5.6	Circulating	Series-connected	
5.7	Remote storage	Close-coupled storage	Integral storage

5.1 a) *Solar Only System* – a system designed to provide solar heated domestic water without use of supplementary energy other than that required for fluid transport and control purposes.

b) *Solar Pre-heat System* – a system not incorporating any form of supplementary heating and installed to preheat cold water prior to its entry into any other type of household water heater.

c) *Solar Plus Supplementary System* – a system which utilizes both solar and an auxiliary energy source in an integrated way and is able to provide a specified hot water service independently of solar energy availability.

5.2 a) *Direct System* – a system in which the heated water that will ultimately be consumed passes through the collector.

b) *Indirect System (Heat Exchange System)* – a system in which a heat transfer fluid other than the heated water ultimately consumed passes through the collector.

5.3 a) *Open System* – a system in which the heat transfer fluid is in extensive contact with the atmosphere.

b) *Vented System* – a system in which contact between the heat transfer fluid and the atmosphere is restricted either to the free surface of a feed and expansion cistern or to an open vent pipe only.

c) *Closed System* (*Sealed or Unvented System*) – a system in which the Heat transfer fluid is completely sealed from the atmosphere.

5.4 a) *Filled System* – a system in which the collector remains filled with the heat transfer fluid.

b) *Drainback System* – a system in which, as part of the normal working cycle, the heat transfer fluid is drained from the collector into a storage vessel for subsequent reuse.

c) *Draindown System* – a system in which the heat transfer fluid can be drained from the collector and run to waste.

5.5 a) *Thermosiphon System* – a system which utilizes only density changes of the heat transfer fluid to achieve circulation between collector and storage.

b) *Forced System* – a system in which heat transfer fluid is forced through the collector either by mechanical means or by externally generated pressure.

5.6 a) *Circulating System* – a system in which heat transfer fluid circulates between the collector and a storage vessel or heat exchanger during operating periods.

b) *Series-Connected System* – a system in which the water to be heated passes directly from a supply point through the collector to a storage vessel or to a point of use.

5.7 a) *Remote Storage System* – a system in which the storage vessel is separate from the collector and is located at some distance from it.

b) *Close-Coupled Collector Storage System* – a system in which the storage vessel abuts the collector, and is mounted on a common support frame.

c) *Integral Collector Storage System* – a system in which the functions of collection and storage of solar energy are performed within the same device.

6 REQUIREMENTS

6.1 Solar domestic hot water systems shall be tested in accordance with the provision set forth in this clause and clause **9**.

6.1.1 *Test Installation Requirements*

Test shall be performed with the system components installed in accordance with manufacturer-published installation instructions. In the absence of specific instructions from the manufacturer and if the collectors are normally mounted remote from the storage, the tests shall be performed with the total connecting pipe length between the storage tank and the collectors a minimum of 15 m (7.5 m in both the supply and return lines). In the case of an air collector array, the total duct length shall be specified by the manufacturer and the total of the duct and pipe length shall be a minimum of 15 m. The connection piping and ducting shall be insulated in accordance with the manufacturer's installation instructions. The collectors shall be mounted at the tilt angle specified by the manufacturer. If the system is to be tested using a non-irradiated solar collector array, a black radiation shield shall be mounted approximately 0.6 m above the collector array and extend approximately 0.6 m beyond the perimeter on all sides. The shield shall consist of very low thermal capacity/insulative capacity material (for example, poster board).

6.1.2 *Solar Collector Performance*

If the system is to be tested using a non-irradiated solar collector array, in series with a conventional heat source, then the collector which is to be used with the solar water heater components to be tested shall have been tested to provide the information required in **9.3.1**.

6.1.3 *Indoor Solar Conditions*

The incident solar radiation conditions to be used in the test shall be as specified for the test solar day (*see* Annex A).

6.1.4 *Ambient Air Temperatures*

6.1.4.1 *Indoor solar conditions*

The average ambient air temperature surrounding the collector array to be used in the test shall be specified for the test solar day (*see* Annex A).

6.1.4.2 The average ambient air temperature at the storage tank and components during the test shall be controlled to a value specified to within ± 3°C on a continuous 24 hour basis (*see* Annex A).

6.1.5 *Input Water Temperature*

The water supply temperature to the system shall be controlled to t_{main} as specified in Annex A within ±0.5°C.

6.1.6 *Water Draw*

Water shall be withdrawn at times and rates as specified (*see* Annex A).

6.1.7 *Wind*

The air flow over the collector array shall be controlled as specified in **8.8.5**.

7 INSTRUMENTATION

7.1 Solar Radiation Measurement

7.1.1 *Radiometers*

A pyranometer shall be used to measure the short wave radiation from the solar irradiance simulator. The pyranometer shall have the following minimum characteristics, which are summarized in Table 1.

7.1.1.1 *Change of response due to variation in ambient temperature*

During the test, the change in the instrument's response due to variation in ambient temperature shall be less than ±1 percent. This specification shall be accomplished using the temperature response curve determined for the specific instrument.

7.1.1.2 *Variation in spectral response*

Pyranometers shall have a constant responsivity to within ±2 percent over the spectral range from 0.3 to 2.5 μm.

7.1.1.3 *Non-linearity of response*

Unless the response of the pyranometer is within ±1 percent of linearity over the range of irradiance existing during the test, the pyranometer shall be used with a calibration curve relating the output to the irradiance with an accuracy of ±1 percent.

7.1.1.4 *Time constant of pyranometer*

The time constant of the pyranometer, defined as the time required for the instrument to achieve a reading of 1 - 1/e = 0.632 of its final reading after a step change in solar irradiance, shall be less than 25 seconds.

Table 1 Summary of Performance Specifications for Solar Radiometers

(*Clause* 7)

	Responsitivity mW/cm²	**Stability** percent	**Temperature Compensation** percent	**Spectral Selectivity** percent	**Linearity** percent	**Time Constant** percent	**Cosine Response** percent
Pyranometer	±0.1	±1.0	±1.0	±2.0	±1.0	<25	>3.0

7.1.1.5 *Variation of response with angle of incidence*

Ideally the response of the pyranometer is proportional to the cosine of the incident angle of the direct solar radiation and is constant at all azimuth angles. Unless the pyranometer's deviation from a true cosine response is less than ±1 percent for the incident angles encountered during the test(s), the pyranometer shall be used with the latest calibration curve relating the response to the angle of incidence with an accuracy within ±1 percent.

7.1.1.6 *Variation of response with tilt*

Unless the pyranometer response varies less than ±1 percent for tilts ranging from horizontal to the largest tilt encountered during the test(s), the pyranometer shall be used with a calibration curve relating the response to the angle of inclination with an accuracy within ±1 percent.

7.1.1.7 *Precautions for effects of temperature gradient*

The instrument used during the test(s) shall be placed in its test position and allowed to equilibrate for at least 30 minutes before data taking commences.

7.1.1.8 *Precautions for effects of humidity and moisture*

The pyranometer shall be provided with a means of preventing accumulation of moisture that may condense on surfaces within the instrument and affect its reading. An instrument with a desiccator that can be inspected is required. The condition of the desiccator should be observed prior to and following any daily measurement sequence.

7.1.1.9 *Precautions for infrared radiation effects on pyranometer accuracy*

Pyranometers used to measure the irradiance of the solar irradiance simulator shall be mounted in such a way as to minimize the effects of the infrared radiation above 3 μm from the simulator light source. This can be accomplished with a ventilator.

7.1.2 *Calibration Interval*

The pyranometer shall be calibrated using a standard pyrheliometer. Any change of the responsivity of more than ±1 percent over a year period shall warrant the use of more frequent calibration or replacement of the instrument if the instability is permanent. If an instrument is damaged in any significant manner, it must be recalibrated to check the stability of the calibration factor and the time constant. In case of a replacement of one of the domes the cosine response should be checked, too.

7.2 Temperature Measurement

7.2.1 *Accuracy and Precision*

The accuracy and precision of the instruments including their associated readout devices shall be within the limits given in Table 2.

7.2.2 *Ambient Temperature*

The ambient air temperature shall be measured using a shaded aspirated sampling device approximately 1.2 m from the floor and not closer than 1.5 m to the tank and system components.

7.2.3 *Time Constant*

In most quasi-steady state test cases the time response of the temperature sensors are of secondary concern. Cases where the response time may be important are during the transient time constant tests and the incidence angle modifier tests are high incident angles using Method 2. From experience, thermocouples and thermopiles with time constants, of less than 1 second are preferred and resistance thermometers with time constants less than 10 seconds are adequate.

7.3 Liquid Flow Measurements

7.3.1 The accuracy of the liquid flow rate measurement, using the calibration if furnished, shall be equal to or better than ± 1 percent of the measured value in mass units per unit time.

7.4 Air Flow Measurement

If the collector is an air heater and the test is being conducted with a non-irradiated array, the air flow in the collector loop shall be measured to an accuracy of ±2 percent or better.

Table 2 Instrument Accuracy and Precision
(*Clause* 7.2)

	Instrument Accuracy	Instrument Precision
Temperature*	± 0.5°C	± 0.2°C
Temperature Difference Across collector (and loop heater, if used)	± 0.1°C	± 0.1°C
Temperature Difference Across hot water System (entering cold water to leaving hot water)	± 0.5°C	± 0.2°C

7.5 Instrumentation Data Recorders

7.5.1 *Instrument Small Scale Division*

In no case should the smallest scale division of the instrument or instrument system exceed 2 times the specified precision. For example, if the specified precision is ±0.1°C, the smallest scale division shall not exceed 0.2°C.

7.5.2 *Data Recorders*

Analog and digital recorders used shall have an accuracy equal to or better than ±0.5 percent of the full scale reading and have a time constant of 1 second or less. The peak signal indication shall be between 50 and 100 percent of full scale.

7.5.3 *Integrators*

Digital techniques and electronic integrators used shall have an accuracy equal to or better than 1.0 percent of the measured value.

7.5.4 *Input Impedance*

The input impedance of recorders shall be greater than 1 000 times the impedance of the sensors or 10 megaohms whichever is higher.

7.6 Electric Energy

The electrical energy used shall be measured with an instrument and associated readout devices that are accurate to within ±1 percent of the reading or 15 Wh whichever is greater.

7.7 Fossil Fuels

The quantity of fuel used for auxiliary energy by the solar hot water system shall be measured with an instrument and association readout device that is accurate within ±1 percent of the reading. Where the supplementary energy is provided from gas, the accuracy of the calorific value of the gas fuel supplied shall be given.

7.8 Mass Measurement

Mass measurement shall be made with an accuracy of ±1 percent.

7.9 Elapsed Time

Elapsed time measurements shall be made to an accuracy of ±0.20 percent.

7.10 Wind Speed

The wind speed shall be measured with an instrument and associated readout device that can determine the integrated average wind speed for each test period to an accuracy of ±0.5 m/s.

8 APPARATUS

8.1 Test Configurations

The test configuration to be utilized is to be determined by the classification of the system as described in **5**. Representative test configuration is shown in Fig. 1 for the case where a non-irradiated collector array is used and the collector loop heater is downstream of the non-irradiated collector array. The purpose of the by-pass loop is to circulate the transfer fluid through the collector loop heater during those times when solar irradiance occurs but the solar domestic hot water system controller does not require the collector loop pump to be on. The by-pass loop pump should not operate when the collector loop is on. For the case where a solar irradiance simulator is used, the heater and by-pass loop shown in the solar collector loop of Fig. 1 shall not be used.

NOTE – Fig. 1 is a schematic only. All components shall be installed according to manufacturer's instructions.

8.2 Storage Tank Mounting

When provided as a separate component, the storage tank(s) shall be placed upon a 19 mm thick plywood platform supported by 50 mm × 100 mm runners. This mounting requirement is necessary for interlaboratory comparisons since heat losses from the bottom of storage tanks can be significant.

8.3 Water Supply

The water supply shall be capable of delivering water at conditions as specified in **6**.

8.4 Water Inlet and Outlet Configuration

The cold water inlet and hot water outlet piping to and from the system being tested shall be turned to a horizontal position in the shortest possible vertical distance practical when the fittings are in a vertical plane. The hot water outlet shall be provided with a quick-acting valve located beyond the point of temperature measurement and as close to the tank as possible.

8.5 Insulation of Piping

Inlet and outlet connections and all piping to the point of temperature measurement in the system being tested shall be insulated with a material having a thermal resistance, R, not less than 0.70°C.m^2/W based on the area of pipe surface.

8.6 Flow Control

A flow control valve shall be installed to provide flow as specified in **9**.

8.7 Installation of Fossil Fuel Fired Auxiliary Energy Sources

Natural draft auxiliary water heaters shall be equipped

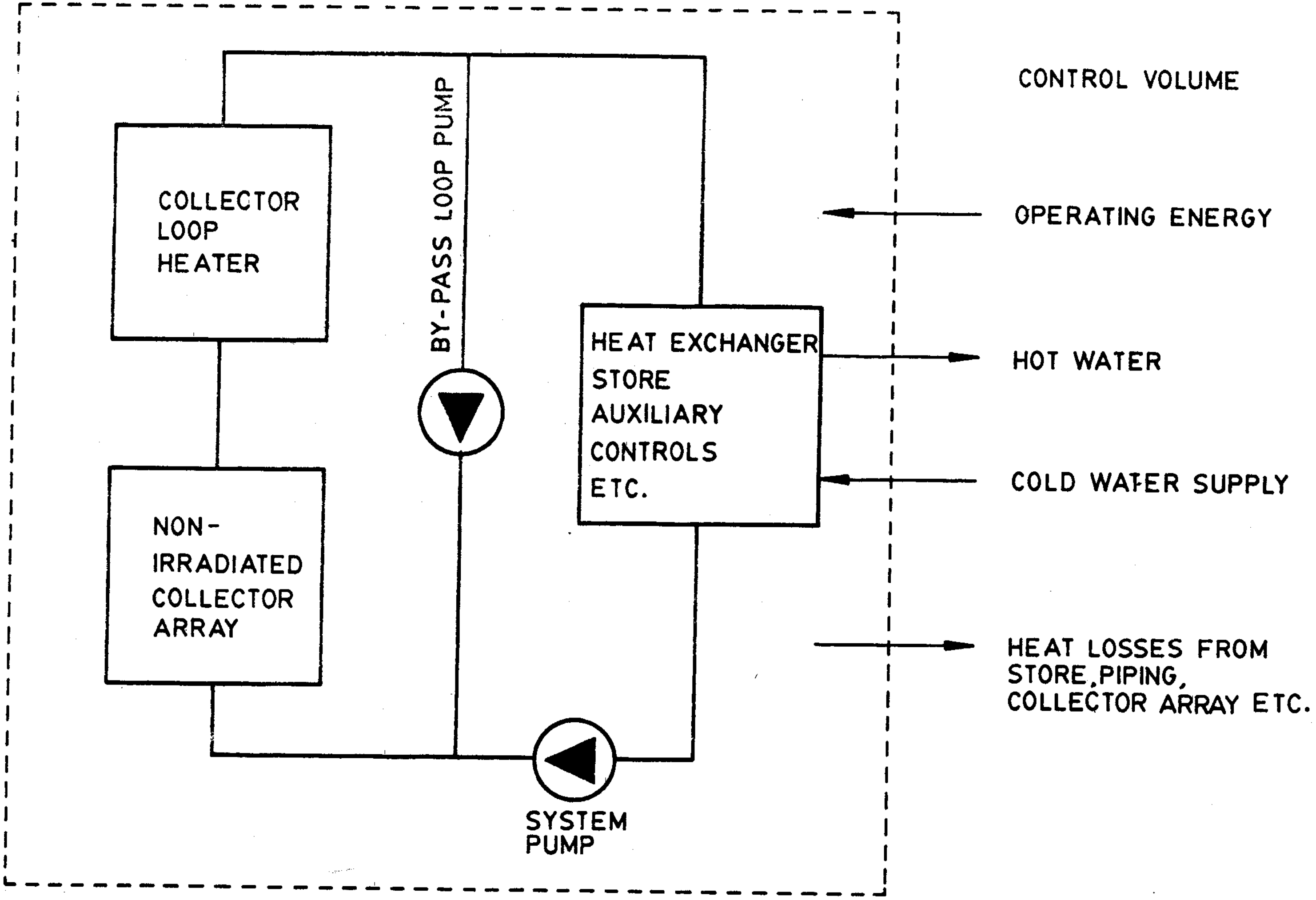
CONTROL VOLUME
COLLECTOR LOOP HEATER
BY-PASS LOOP PUMP
OPERATING ENERGY
HEAT EXCHANGER STORE AUXILIARY CONTROLS ETC.
HOT WATER
COLD WATER SUPPLY
NON-IRRADIATED COLLECTOR ARRAY
HEAT LOSSES FROM STORE, PIPING, COLLECTOR ARRAY ETC.
SYSTEM PUMP

FIG. 1 SCHEMATIC REPRESENTATION OF EXPERIMENTAL APPARATUS FOR INDOOR TEST WITH NON-RADIATED COLLECTOR ARRAY

with a vertical extension of flue pipe connected to the draft hood outlet pipe as specified by the prevailing building code. In the absence of a building code, use the manufacturers specifications.

8.8 Indoor Testing with a Solar Irradiance Simulator

A solar irradiance simulator may be used in lieu of indoor testing using a non-irradiated collector array in series with a conventional heat source to determine the steady state thermal performance of a solar collector under controlled conditions of wind and ambient temperature.

Solar simulators employed in the testing procedure shall have the following minimum characteristics and shall be used in accordance with the noted guidelines and limitations.

8.8.1 *Spectral Qualities*

The simulator shall provide a spectral distribution of irradiance which duplicates the standard global radiation spectrum for air mass 1.5 and a total irradiance of 952 W/m^2. Annex C gives the spectral distribution related to the total irradiance for 100 wavelengths.

The quality of simulation must meet the following requirement : The spectrum-weighted value of the transmittance-absorptance product at normal incidence or any other product of optical properties that characterises the collector under test, calculated using the measured solar simulator spectrum shall not differ by more than 3 percent, from the value of the transmittance-absorptance product calculated using the standard spectrum. The relevant spectral optical properties shall be provided by the manufacturer of the collector under test. A method of calculating spectrum-weighted values is presented in Annex D. Spectrum-weighted values of the optical properties shall be reported for both the standard and solar simulator spectrum.

Measurement of the solar simulator's spectral qualities shall be in the plane of the collector over the wavelength range of 0.3 - 3 µm and shall be determined in 0.1 µm or smaller bandwidths.

Solar simulator spectral measurements shall be obtained for each new set of lamps installed. With certain lamp types, such as filament lamps, the simulator spectrum may change significantly during the lifetime of the lamps. Measurements should be made as necessary in order to ensure that the calculated spectrum weighted value of the transmittance-absorptance product for the system under test does not differ by more than 3 percent from the value calculated using the standard spectrum.

8.8.2 *Measurement of Test Irradiance and Irradiance Uniformity*

The simulated solar irradiance shall be measured in the test plane of the solar collector. The test plane shall be taken as the front cover of a glazed flat plate collector. The test plane shall be taken as the front cover of a glazed flat plate collector, the absorber plate of an unglazed flat plate-collector or the aperture plane of a concentrating collector. The collector array may be shaded during this measurement provided the shaded area is • less than three percent of the irradiated collector area during any hourly simulation period.

Since simulated solar radiation usually varies somewhat in intensity over the collector aperture, the value of irradiance over the test plane shall be representative of the average of measurements of irradiance taken on a uniform rectangular grid of maximum spacing of 15.0 cm. The instrument used to measure the test plane irradiance shall be equivalent to that specified for outdoor testing or other instruments calibrated in the simulated solar radiation against such a device. The uniformity of the irradiance shall be such that the highest and lowest measure of values of irradiance shall not deviate from the average value by more than ±10 percent.

Also, variations in the irradiance may occur during the test interval due to instability of the electrical supply and changes in the lamp output with temperature and age. The average value of irradiance shall not vary by more than ±2 percent over the duration of the test interval. The value of irradiance reported and used in the calculation of thermal performance shall be representative of the mean of the values experienced over the duration of each test interval.

8.8.3 *Collimation*

For typical flat plate collectors, the collimation shall be such that at least 90 percent of the energy received at any point in the collector test plane shall have emanated from a region of the solar simulator contained within a subtended angle of 20 degrees or less, when viewed from the point. This constraint limits the use of simulators to concentrating collector with concentration ratios less than 3:1. However, it should be noted that a higher degree of collimation may be required for certain concentrating collectors particularly those with the higher concentration ratios (near 3 : 1) and for collectors composed of glass tubes, such as the evacuated tubular collectors. In these cases it must be demonstrated that there is sufficient collimation relative to the collector. This might be demonstrated by indoor and outdoor test correlations.

8.8.4 *Indoor Ambient Air Temperature*

The ambient temperature sensor shall be housed in an asperated enclosure located behind the collector under test and shielded from direct irradiance.

8.8.5 *Air Flow Across Collector(s) Indoor Test*

Fans or other means shall be used to simulate a substantially uniform flow across the collector during the pretest steadying and actual test periods. The temperature of the flowing air shall be within ±1.0 °C of the ambient temperature measured as prescribed in **8.8.4**. The air flow direction shall originate in a horizontal plane and directed towards the collector within 30 degrees from the vertical plane containing the centrelines of the test collector (array). This simulated wind shall be maintained at a mean speed of 4.0 (±0.5) m/s and shall be measured before and after each test period in a plane parallel to the collector aperture and between 50 and 150 mm from the outer cover of the collectors. The air speed measurement is to be an average value measured over at least the centre one-square-meter of the aperture with a non-uniformity of not more than ±0.5 m/s of the mean value.

8.8.6 *Ambient Temperature Variations*

The allowable range of the ambient temperature for solar simulator testing shall be between 15°C and 30°C. During any test period, the ambient temperature shall not vary by more than ±2°C.

8.8.7 *Tilt Angle*

The tilt angle of the collector during testing shall be as specified by the manufacturer of the collector. The specified tilt angle shall remain constant throughout the test.

8.8.8 *Long Wave Radiation*

The long wave (thermal) irradiance between 4 μm and 50 μm shall be measured in the plane of the collector aperture by a pyrgeometer or other equivalent instrument. The long wave irradiance as measured during the test in the plane of the collector aperture shall not exceed that from a theoretical black body at ambient temperature by more than 50 W/m^2.

8.8.9 *Solar Irradiance Simulator Incident Angles*

During simulation, the incident angle shall not exceed 60°. The incident angle during test shall be within 5° of the specified incident angle for a given hour of the test day (*see* Annex A).

8.9 Indoor Testing with a Non-irradiated Collector Array in Series with a Conventional Heat Source

A non-irradiated array in series with a conventional heat source may be used to simulate an irradiated solar collector array in lieu of using a solar irradiance simulator as described in **8.8**. The collector is tested separately to provide the information required in **9.3.1** and the array's thermal output in the system test is obtained by using a combination of the non-irradiated collector array and a heat source in series in the collector loop.

8.9.1 *Collector Controller Temperature Sensor*

The temperature sensor designed to be installed on or in the vicinity of the solar collector array and connected to the system controller for starting and stopping the collector loop pump or blower shall be installed on the surface or inside of the pipe or duct (under the insulation) downstream of the non-irradiated array and collector loop heater but as close to the exit of the second device as is practical.

8.9.2 *Electric Heaters*

If an electrical heating element is used in the collector loop heater, the heating element shall be immersed in the fluid stream of the transfer fluid and the thermal losses shall be less than 2 percent of the input. Under these conditions, the measured collector heater input can be taken as the heater output. If the losses are more than 2 percent of the input, a means of measuring the energy delivered to the fluid by the heater shall be provided.

8.9.3 *Peak Thermal Output*

The collector loop heater shall be sized to deliver the peak rate of solar collector absorbed energy.

8.9.4 *Pressure Drop*

The pressure drop across the collector loop heater shall be less than the pressure drop in an equivalent 6 m length of pipe or duct in the collector loop.

8.9.5 *Time Constant*

The time constant of the collector loop heater shall be less than 2 minutes.

9 EXPERIMENTAL DETERMINATION

9.1 Introduction

Procedures are described in this section for testing the performance of three categories of solar domestic hot water systems; solar-only systems, solar-preheater systems, and solar-plus-supplemental systems. The test can be done by assembling the complete system and irradiating the collector array by use of a solar irradiance simulator as described in **9.2**. Alternately, the collector arrray may be non-irradiated if a controlled heating device (collector loop heater) is added in series with the collector array as described in **9.3**. For either case, the system shall be tested for a test day with no solar input.

9.2 Indoor Testing with Solar Irradiance Simulator

9.2.1 *Solar Irradiance Simulator Output*

The daily total integrated irradiance shall be within ±5 percent of the specified daily irradiation for the testing day as given in Annex A and Annex E.

9.3 Indoor testing with a non-irradiated solar collector array in series with conventional heat source. If the non-irradiated solar collector array is used, it shall meet all the requirements of **8.9**.

9.3.1 *Separate Test for the Solar Collector*

The solar collector shall have been previously tested in accordance with IS 12933 (Parts 1 to 5) : 1990 on :

a) a curve of collector efficiency as a function of $(t_{f,i} - t_a)/G_t$ with the collector operating at near-normal incidence to the beam of the sun.

b) a curve of incident angle modifier as a function of incident angle q or the parameter [(1/Cos q) — 1].

c) the mass flow rate and the specific heat of the fluid used during the collector tests.

The collector heat transfer fluid used in the solar water heating system shall be the same as that used in the collector tests.

9.3.2 *Control of the Collector Loop Heater*

The thermal output of the collector loop heater is calculated and changed in accordance with the time intervals (*see* Annex A and Annex E) specified by the test day using the equations governing their thermal output (*see* Annex B) and the values of $t_{f,i}$, m_s, and $c_{p,s}$ that are measured (or calculated) prior to every change in input energy.

9.3.3 *Collector Loop Thermal Output*

The collector loop thermal output, $t_{f,i}$, and m_s, should all be monitored as a function of time during the test. After the test is completed, a calculation of total daily collector array thermal output is required using the known variation of G_t and t_a throughout the test solar day, the measured values of $t_{f,i}$ and m_s, and the collector thermal performance characteristics determined from the collector tests. The measured value of total daily collector loop thermal output from the system test must be within ±5 percent of this calculated value.

9.3.4 Calculation procedure for the collector loop heater thermal output. The calculation procedure to determine the desired thermal output of the collector loop heater is as follows:

a) The incident radiation on the collector surface, G_t, is specified as a function of time for the test solar day (*see* Annex A).

b) The incident angle is specified or calculated as a function of time throughout the test day (*see* Annex A).

c) Using the results of step (b) and the incident angle modifier data the incident angle modifier is calculated as a function of time throughout the day.

d) The value of F_R is calculated as a function of time throughout the test day using equation (B.24).

e) The quantity Q_{lh} is calculated as a function of time throughout the test day using equation (B.15).

9.4 Solar-Only and Solar-Preheat System Test

9.4.1 *Purpose*

The purpose of this test is to determine the performance of a solar-only hot water system or of a solar-preheat hot water system. This test may also be used to consider the "solar-only" performance capabilities of a system that has supplementary heating.

9.4.2 *Test Procedure*

The storage device(s) shall be filled with water at a specified temperature, on the morning of the first day (*see* Annex A). The system shall be energized and shall be allowed to operate in its normal mode during the day and each successive day of the test. Any device which is intended to limit or control the operation of the solar energy collection equipment shall be set as recommended by the manufacturer. On each test day, water shall be withdrawn from the system at times, rates, and duration as specified for the test day (*see* Annex A). The energy content of the water withdrawn shall be determined by installed flowmeters and temperature sensors. The delivery temperature shall be measured and recorded at no greater than 4.5 kg intervals throughout the withdrawal period (*see* Annex A).

The test shall be performed until the daily system solar contribution (*see* equation 9.3) is within three percent (± 3 percent) of the value on the previous test day. If after the end of the fourth test day this convergence criteria is not met, data for day 5 has to be obtained. Then stop the test and average the data for days 3, 4 and 5.

9.4.3 *Measurements*

During the test period, measurements of the daily energy consumed by the circulation system (pumps, controls, solenoid valves, etc) shall be made, and daily thermal energy output from the collector loop heater (if used) shall be determined from measurements. These shall be recorded at the end of each test day. The energy consumed by the by-pass loop controls, pump, fan, and valves if measured shall be obtained separately from the energy consumed by the solar domestic hot water system components. During the withdrawal period, the mixed temperature of the incoming water and the mass and mixed temperature of each withdrawal shall be measured. If the collector loop heater is used, the thermal energy output from the heater, the mass flow rate through the collector array, the entering fluid temperature, temperature increase across the collector loop which consists of the non-irradiated solar collector array and conventional heat source shall all be determined for time intervals specified by the test day (*see* Annex A).

9.4.4 *Calculation*

The daily system hot water load shall be calculated as :

$$Q_L = \sum_{j=1}^{n} C_{p,w} (t_{set} - t_{main}) m_j \qquad \text{.... (9.1)}$$

The daily net energy supplied by the solar energy shall be calculated as :

$$Q_S = \sum_{j=1}^{n} C_{p,w} (t_{s,j} - t_{main}) m_j \qquad \text{.... (9.2)}$$

The solar contribution is given as :

$$S_C = Q_S/Q_L \qquad \text{...... (9.3)}$$

All measurements used in this calculation shall be those for the final test day when convergence according to **9.4.2** is met. Otherwise average the data for days 3, 4 and 5.

9.5 Solar Hot Water System Test with Integral Supplement Heaters

9.5.1 *Purpose*

The purpose of this test is to determine the performance of a solar hot water system with integral supplemental heaters (solar plus supplementary system) for both a test day with solar energy input and a test day with no solar energy input.

9.5.2 *Test Procedure with Solar Energy Input*

The storage device(s) shall be filled with water at a specified temperature (*see* Annex A) on the morning of the first day. The system shall be energized, including integral heaters and controls, and shall be allowed to operate in its normal mode during the day and each successive day of the test. The time for the beginning of the first and subsequent 24 hour test days shall be specified by the test day (*see* Annex A). Any device which is intended to limit or control the operation of the solar energy collection equipment shall be set as recommended by the manufacturer. If the system is designed so that the temperature of the delivered water is controlled by a thermostatic control on the auxiliary energy delivery system, this thermostat shall be set to deliver water at t_{set}. If the system is designed so that the temperature of the delivered water is contolled by a mixing valve, the mixing valve shall be set to deliver water at t_{set} and the control of the auxiliary heating system shall be set as recommended by the manufacturer. On each test day, water shall be withdrawn from the system at times, rates, duration, and temperature, t_{set}, as specified by the test day (*see* Annex A). If the outlet water temperature from the system is not maintained at t_{set}, an energy integrator may be used and the length of the time of the draw adjusted so that the same total amount of thermal energy output, measured above t_{main}, is delivered. The energy content of the water withdrawn shall be determined by the used of an installed flow meter and temperature sensors. The delivery temperature shall be measured and recorded at no greater than 4.5 kg intervals throughout the withdrawal period. The solar energy input (by **9.2** or **9.3**) shall follow the specifications given in Table 5.

The test shall be performed until the daily system supplemental energy required (Q_{AUX}) is within 3 percent of the value on the previous test day. If after the end of the fourth test day, this convergence criteria is not met, data for day 5 has to be obtained. Then stop the test and average the data for days 3, 4 and 5.

9.5.3 *Test Procedure with no Solar Energy Input*

All of the specifications in **9.5.2** shall be followed except that there shall be no solar energy input.

9.5.4 *Measurements*

For each test day, measurements of the daily energy consumed by the circulation system (pumps, controls, solenoid valves, etc) and the energy consumed for auxiliary heating shall be recorded and reported (*see* Annex A). The energy consumed by the by-pass loop controls, pump, fan, and valves if applicable shall be obtained separately from the energy consumed by the solar domestic hot water system components. The daily thermal energy output from the collector loop heater (if used) shall also be determined from measurements. All daily quantities shall be recorded at the end of each test day. During the withdrawal periods, the mixed temperature of the incoming water and the mass and mixed temperature of each withdrawal shall be measured. If the collector loop heater is used, the thermal energy output from the heater, the mass rate through the collector array, the entering fluid temperature, temperature increase across the collector loop which consists of the non-irradiated solar collector array and conventional heat source shall all be recorded for time intervals specified by the test day (*see* Annex A).

9.5.5 *Calculations*

The daily system hot water load with and without solar energy input shall be calculated respectively, as

$$Q_{LS} = \sum_{j=1}^{n} c_{p,w} (t_{w,j} - t_{main}) m_j \quad \text{with solar input} \qquad \text{.... (9.4)}$$

$$Q_{L,NS} = \sum_{j=1}^{n} c_{p,w} (t_{w,j} - t_{main}) m_j \quad \text{without solar input} \qquad \text{.... (9.5)}$$

A rating number R has been defined and is given by

$$R = (Q_{AUX,S} + Q_{PAR,S})/Q_{L,S} \qquad \text{.... (9.6)}$$

The daily net energy supplied by solar energy can be estimated by

$$Q_S = Q_{L,S} + Q_{LOS} - Q_{AUX,S} - Q_{PAR,S} \qquad \text{.... (9.7)}$$

where

$$Q_{LOS} \approx (Q_{AUX,NS} + Q_{PAR,NS}) - Q_{L,NS} \qquad \text{.... (9.8)}$$

NOTE — The actual Q_{LOS} is a function of the temperature distribution in the store(s) which may be quite different when there is solar energy input. Hence, the solar contribution is only a good estimate without knowing Q_{LOS} during the test day with solar input.

The performance of the solar system shall be determined and reported using procedures in Annex A and Table 4.

9.6 Hot Water — Continuous Draw Test

9.6.1 *Hot Water — Solar Energy Only*

9.6.1.1 *Purpose*

The purpose of this test is to determine the capability of the solar hot water system to deliver hot water with no auxiliary energy source operating and during a continuous draw-down.

9.6.1.2 *Test Procedure*

The solar hot water system shall be installed, adjusted, and operated as described in **9.4.2** or **9.5.2**. Ten minutes after the last draw on the final test day, a special draw test shall be conducted. All auxiliary energy source thermostats (if any) shall be disabled. The cold water supply shall be adjusted to supply water at t_{main} ± 1.0°C. Water shall be withdrawn at a uniform flow rate as specified in the test day (*see* Annex A).

9.6.1.3 *Measurements*

The temperature of the water shall be measured at a point as close to the storage tank(s) as possible and recorded immediately at the start of the draw and at not less than 4.5 kg intervals thereafter. The draw shall continue until the discharge temperature equals the inlet temperature within 3.0°C.

9.6.1.4 *Calculations*

A curve with outlet water temperature as the ordinate and quantity of water withdrawn as the abscissa shall be drawn using the test results.

10 DATA TO BE RECORDED AND TEST REPORT

10.1 Test Data

Table 3 lists the measurements which are to be made throughout the tests to determine the fraction of the daily total hot water load supplied by solar energy.

10.2 Table 4 specifies the data and information that shall be reported in testing the solar domestic hot water system.

Table 3 Measurements to be Made and Test Data and Information to be Recorded

(*Clause* 10.1)

Item	Test Involving Solar-Only or Solar-Preheat Systems	Test Involving Solar-Plus-Supplemental Systems
Date	X	X
Observers	X	X
Equipment name plate data for system components	X	X
Number of collectors in system.	X	X
Collector aperture area, m^2	X	X
Collector gross area, m^2	X	X
Storage tanks' outside dimensions, m	X	X
Storage tanks' volumetric capacity, m^3	X	X
Number and location of integral heating elements		X
Rating of integral heating elements		X
1) Mass flow rate through collector during the collector tests, m_c, kg/s	X	X
1) Specific heat of heat transfer fluid used during the collector tests, $c_{p,c}$ kJ (kg.°C)	X	X
1) Intercept of the collector efficiency curve determined in accordance with collector tests, $(\lambda_s/\lambda_g) F_R (\tau\alpha)_{c,n}$, dimensionless	X	X
1) Slope of the collector efficiency curve determined in accordance with collector tests determined at a value of $(t_{set} - t_{a,t})/G_t$ at solar noon during the system test, $\lambda_s/\lambda_g F_R U_L$, kJ/(h.m².°C)	X	X
1) The effective transmittance-absorptance product at normal incidence as specified in Section 8 (and Annex B) of this standard, $(\tau\alpha)_{c,n}$, dimensionless	X	X
1) Collector heat removal factor as determined in Annex B of this standard, F_R, dimensionless	X	X
1) Collector overall heat transfer coefficient as determined in Annex B of this standard, U_L, kJ/(h.m².°C)	X	X
1) Collector efficiency factor as determined in Annex B of this standard, F', dimensionless	X	X
1) Mass flow rate of the transfer fluid through the solar collector array during the system test (recorded at the specified time increments) m_s, kg/s	X	X
1) Specific heat of the transfer fluid through the solar collector array during the system test (determined at the specified time increments) $c_{p,s}$, kJ/(kg. °C)	X	X
1) Temperature of the transfer fluid entering the solar collector array during the system test (recorded at the specified time increments) $t_{f,i}$, °C	X	X
1) Temperature difference across the solar collector loop during the system test (recorded at the specified time increments) $(t_{f,e} - t_{f,i})$, °C	X	X
1) Ambient air temperature surrounding the system during the test (recorded at the specified time increments) $t_{a,l}$, °C	X	X
1) Energy output from the collector loop heater (if used) during the test (recorded at the specified time increments), Q_{OUTPUT}, kJ	X	X
Energy consumed for auxiliary heating (recorded at the specified time increments), kWh		X
Inlet water temperature to the system during the test (recorded during every draw), t_{main}, °C	X	X
Outlet water temperature from the system during the test (recorded during every draw), $t_{w,j}$, °C	X	X
Mass of water withdrawn from the system during the test (recorded during every draw), m_j, kg	X	X
1) Daily energy output from the collector loop heater (if used), Q_{OUTPUT}, kJ	X	X
Daily energy consumed by the system's circulation and control apparatus (pumps controls, solenoid valves, etc), Q_{PAR}, kJ	X	X
Daily energy consumed for auxiliary heating Q_{AUX}, kJ		X

1) Only to be recorded if the collector loop heater is used.

Table 4 Data Information to be Reported

(*Clause* 10.2)

General Information

Name of Manufacturer

Solar Domestic Hot Water System No. :

Construction details of the system :

collector aperture dimensions and area, m and m^2

collector gross dimensions and area, m and m^2

number of collectors in system

$(A_a/A_g)F_R(\tau\alpha)_{e,n}$ (From collector tests)

$(A_a/A_g)F_R U_L$ determined at a value of $(t_{set} - t_{a,t})/G_t$ at solar noon during the system test (from collector tests)

storage tank dimensions including insulation thickness, m

Diameter	Height	Insulation Thickness

description of the solar domestic hot water system including insulation, valves, circulation, piping, controls, and control set points

Transfer fluid used and its thermal-physical properties (specific heat, density, viscosity)

Specific heat :	Density :	Viscosity :

Description of test apparatus, including configuration and instrumentation used in testing (include photographs). For a thermosiphon system, include the piping size and elevation of the storage tank above the solar collector array

Tests

The solar contribution shall be determined and reported for the system under test.

At the beginning of the tests to determine solar contribution and thereafter in time increments specified in the test day, the following shall be reported if the collector loop heater is used :

Q_{output} kJ

$t_{f,i}$ °C

$\dot{m}_s$ kg/s

Table 4 (*Concluded*)

For each withdrawal of water from the system during the tests to determine solar contribution, the following shall be reported :

m_j ______________________ kg

$t_{w,j}$ ______________________ °C

t_{main} ______________________ °C

On a daily basis during the test to determine solar contribution the following shall be reported :

$Q_{L,NS}$ ______________________ kJ

$Q_{L,S}$ ______________________ kJ

$Q_{AUX,NS}$ ______________________ kJ

$Q_{AUX,S}$ ______________________ kJ

$Q_{PAR,NS}$ ______________________ kJ

$Q_{PAR,S}$ ______________________ kJ

Q_{LOS} ______________________ kJ

Q_S ______________________ kJ

R ______________________

For the hot water supply rating tests, a curve of outlet water temperature as the ordinate and quantity of water withdrawn as the abscissa shall be reported both with (if appropriate) and without the use of the auxiliary energy source.

NOTE — Annex A is a mandatory part of the test report.

ANNEX A

(Normative)

(*Clauses* 6, 8, *and* 9)

DAY TEST SPECIFICATIONS

This Annex provides a standardized set of test conditions for comparing the performance of different domestic water heating systems.

Energy Load or Energy Content of Hot Water Delivered by System

$\dot{Q}_L$ Solar only $= \Sigma \dot{m}_j c_{p,w} (t_{set} - t_{main})$

$\dot{Q}_L$ Solar Pre-heat $= \Sigma \dot{m}_j c_{p,w} (t_{set} - t_{main})$

$\dot{Q}_L$ Solar Plus Supplemental $= \Sigma \dot{m}_j c_{p,w} (t_{w,j} - t_{main})$

Energy Supplied by Solar Energy

$\dot{Q}_S$ Solar Only $= \Sigma \dot{m}_j c_{p,w} (t_{s,j} - t_{main})$

$\dot{Q}_S$ Solar Pre-heat $= \Sigma \dot{m}_j c_{p,w} (t_{s,j} - t_{main})$

$\dot{Q}_S$ Solar Plus Supplemental $= \Sigma \dot{m}_j c_{p,w} (t_{s,j} - t_{main})$

Preheating System Before Starting Test

The test period can be shortened by at least one day if the system is preheated with 45°C water.

Clock Time for Beginning Test

Since the test is done indoors, the time for beginning each 24-hour period is arbitrary. However, in the rating day specifications given below, the clock time for beginning the first and subsequent test days for energy calculations is 1 700 hours.

Example

Collector Tilt Angle	45°C from horizontal unless manufacturer specifies a different value
Average Ambient Air Temperature, t_a	20 ± 2°C
Input Water Temperature, t_{main}	15 ± 2°C
Set Temperature for Auxiliary Tank, t_{set}	Specified by the manufacturer but not less than 49°C
Water Draw Rate	10 ± 1 l/minute
Wind Speed	*See* **8.8.5**
Water Draw Schedule	*See* Table 5. Five equal volume draws for a total draw of 100, 200 or 300 l shall be used. For solar plus auxiliary systems, determine the draw volume during the no solar input test (*see* **9.2**). In performing this test, first establish equalibrium. Take first draw at the specified flow rate. Monitor delivery temperature. Record the volume at which the temperature drops to 35°C. Choose the daily draw volume as being that which is immediately below the volume at which the temperature dropped to 35°C. For solar only systems, test volume shall be selected by the manufacturer from 100, 200 or 300 l. The laboratory shall test for the specified conditions and measure/monitor the temperature during the draws. The solar energy contributed and the quantity of energy below and above 35°C delivery temperature shall be recorded with the results.
Solar Radiation Schedule	*See* Table 5. Diffuse irradiance is constant at 160 W/m² throughout the solar day.

Table 5

(*Clause* 9.5.2)

Conditions for Thermal Performance Test of SDHW Systems

Time (h)	Incident Radiation			Hour Angle, w (°)	Incident Angle, θ (°)	Load (litres)
	Non-solar Day kJ/(m².h)	Solar Day G_{bp} kJ/(m².h)	Solar Day G_d kJ/(m².h)			
0 800-0 900	0	694	576	-60	60	0.2V
0 900-1 000	0	1,224	576	-45	45	
1 000-1 100	0	1,624	576	-30	30	
1 100-1 200	0	1,884	576	-15	15	
1 200-1 300	0	1,964	576	0	0	0.2V
1 300-1 400	0	1,884	576	15	15	
1 400-1 500	0	1,624	576	30	30	
1 500-1 600	0	1,224	576	45	45	
1 600-1 700	0	694	576	60	60	0.2V
1 700-1 800						0.2V
1 800-1 900						
1 900-2 000						0.2V
Total	0	12,816	5,184			V

ANNEX B

(Normative)

(*Clauses* 8 *and* 9)

SPECTRUM DISTRIBUTION

Use of a non-irradiated solar collector array in the solar domestic hot water system test.

As outlined in the solar hot water system may be tested in the laboratory using a non-irradiated solar collector array with a collector loop heater installed downstream of the array and controlled to supply the collector absorbed energy to the flow loop. The purpose of this Annex is to derive the governing equations to be used in controlling the thermal output of the heater.

The thermal performance of an irradiated solar collector operating under quasi-steady-state conditions can be described by either of the following equations :

$$\frac{\dot{Q}_u}{A_a} = K_{\alpha\tau} F_R (\tau\alpha)_{e,n} G_t - F_R\ U_L(t_{f,i} - t_a) \qquad \text{.......... (B.1)}$$

or

$$\frac{\dot{Q}_u}{A_a} = K_{\alpha\tau}\ (\tau\alpha)_{e,n} G_t - U_L(t_{p,m} - t_a) \qquad \text{.......... (B.2)}$$

Equating the two equations and solving for $t_{p,m}$

$$\text{tp,m} = F_R\ (t_{f,i} - t_a) + \frac{K_{\alpha\tau} G_t (\tau\alpha)_{e,n}}{U_L}\ (1 - F_R) + t_a \qquad \text{........ (B.3)}$$

If the collector were in the laboratory and not irradiated, equation (B.3) would reduce to :

$$t_{p,m,non} = F_R\ (t_{f,i} - t_{a,l}) + t_{a,l} \qquad \text{........ (B.4)}$$

The above equations can be used to derive the equations for the required net energy output of a collector loop heater that will result in the same performance as with the irradiated collector.

Collector loop heater downstream of the non-irradiated collector array.

In order for the net energy output for the collector loop to be the same when using a collector loop heater and non-irradiated collector compared to the use of an irradiated collector:

$$\frac{Q_{lh}}{A_a} - U_L\ (t_{p,m,non} - t_{\alpha,l}) = K_{\alpha\tau} F_R\ (\tau\alpha)_{e,n} G_t - F_R U_L\ (t_{f,i} - t_{a,t}) \qquad \text{........ (B.5)}$$

The left side of the equation (B.5) represents the net energy output from the collector loop in the laboratory when the collector loop heater supplies energy to the loop and heat loss occurs from the non-irradiated collector. The right side of the equation represents the net output that would occur from an irradiated collector. Note that the loss coefficient for the collector, U_L, is assumed to be the same for both configurations. Since the collector loop heater is downstream of the non-irradiated collector, the inlet fluid temperature to the non-irradiated collector is identical to the inlet fluid temperature that would occur with the irradiated collector. Consequently, equation (B.4) can be introduced into the left side of equation (B.5) and the resulting equation solved for $\dot{Q}_{lh}$:

$$\dot{Q}_{lh} = K_{\alpha\tau} \frac{A_a}{A_g} F_R\ (\tau\alpha)_{e,n} G_t A_g - \frac{A_a}{A_g} F_R U_L A_g (t_{a,l} - t_{a,t}) \qquad \text{........ (B.6)}$$

Equation (B.6) is for a one-collector module array. The analysis is readily extended to combination of M parallel rows of N collectors connected in series. Consider the situation where there are M collectors connected in parallel and no collectors connected in series (N = 1). Equation (B.6) becomes:

$$Q_{lb} = K_{\alpha\tau} \frac{A_a}{A_g} F_R (\tau\alpha)_{e,n} G_t M A_g - \frac{A_a}{A_g} F_R U_L M A_g (t_{a,l} - t_{a,t}) \qquad \text{........ (B.7)}$$

Collector modules connected in series requires that the heat removal factor, F_R, in equation (B.7) be modified. For one solar collector module :

$$F_R = \frac{m c_p}{U_L A_a} \left[1 - \exp - \frac{A_a F' U_L}{m c_p} \right] \qquad \text{........ (B.8)}$$

Where two collector modules are connected in series, each module has the same mass flow rate; however, the aperture area is doubled. With the assumption that U_L and F are equal for the two collectors, equation (B.8) becomes :

$$F_{R2} = \frac{\dot{m} c_p}{U_L 2 A_a} \left[1 - \exp - \frac{A_a F' U_L}{m c_p} \right] \qquad \text{........ (B.9)}$$

Algebraic manipulation of equation (B.8) and equation (B.9) yields :

$$F_{R2} = F_R \left[1 - \frac{(A_a/A_g) F_R U_L A_g}{2 \dot{m} c_p} \right] \qquad \text{............... (B.10)}$$

Thus for two collectors in series :

$$(F_R U_L)_2 = (F_R U_L) \left[1 - \frac{(F_R U_L) A_a}{2 \dot{m} c_p} \right] \qquad \text{........(B.11)}$$

and

$$[F_R (\tau\alpha)_{e,n}]_2 = [F_R (\tau\alpha)_{e,n}] \left[1 - \frac{(F_R U_L) A_a}{2 \dot{m} c_p} \right] \qquad \text{........(B.12)}$$

Generalizing to any number, N, of identical collectors in series:'

$$(F_R U_L)_N = \frac{\dot{m} c_p}{N A_a} \left[1 - \left(1 - \frac{(F_R U_L) A_a}{2 \dot{m} c_p} \right)^N \right] \qquad \text{........(B.13)}$$

and

$$[F_R (\tau\alpha)_{e,n}]_N = \frac{[F_R (\tau\alpha)_{e,n}] \dot{m} c_p}{(F_R U_L) A_a} \left[1 - \left(1 - \frac{(F_R U_L) A_a}{\dot{m} c_p} \right)^N \right] \qquad \text{............... (B.14)}$$

Therefore, in the most general case where the heat source is located downstream of M rows of N collectors connected in series :

$$\dot{Q}_{lb} = K_{\alpha\tau} \frac{A_a}{A_g} [F_R (\tau\alpha)_{e,n}] G_t MN A_g - \frac{A_a}{A_g} (F_R U_L)_N MN A_g (t_{a,l} - t_{a,t}) \qquad \text{........(B.15)}$$

Collector loop heater upstream of the non-irradiated collector array.

Equating the net energy output from the collector loop for the two alternate test configurations (collector loop heater plus non-irradiated collector and irradiated collector) as was done above,

$$\frac{\dot{Q}_{lb}^*}{A_a} - U_L (t^*_{p,m,non} - t_{a,l}) = K_{\alpha\tau} F_R (\tau\alpha)_{e,n} G_t - F_R U_L (t_{f,i} - t_{a,t}) \qquad \text{........(B.16)}$$

The * indicates that $t_{p,m,non}$ is different from the previous case because the collector loop heater is now upstream of the irradiated collector. Equation (B.4) is still valid except the inlet fluid temperature to non-irradiated collector is also different from the previous case due to the location of the collector loop heater :

$$t^{*}_{p,\,m,\,non} = F_R\,(t^{*}_{f,\,i} - t_{a,\,l}) + t_{a,\,l} \qquad \text{........(B.17)}$$

An energy balance on the collector loop heater results in the following expression for the exit fluid temperature from the heater (inlet fluid temperature to the non-irradiated collector, $t^{*}_{f,\,i}$) in terms of the inlet fluid temperature to the heater (identical to the inlet fluid to the non-irradiated collector in the previous case, $t_{f,\,i}$) :

$$t^{*}_{f,\,i} = t_{f,\,i} + \frac{\dot{Q}_{lh}^{*}}{\dot{m}_s\,c_{p,s}} \qquad \text{...... (B. 18)}$$

Solving equations (B.16), (B.17) and (B.18) simultaneously :

$$\dot{Q}_{lh}^{*} = \frac{K_{\alpha\tau}\,(A_a/A_g)\,F_R\,(\tau\alpha)_{e,\,n}\,G_t\,A_g - (A_a/A_g)\,F_R U_L\,A_g\,(t_{a,\,l} - t_{a,\,t})}{1 - [(A_a/A_g)\,(F_R U_L)\,A_g]/[m_s\,c_{p,s}]} \qquad \text{........(B.19)}$$

Equation (B.19) is for a one collector module array. For the case where there are M collectors connected in parallel and no collectors connected in series (N = 1), equation (B.19) becomes :

$$\dot{Q}_{lh}^{*} = \frac{K_{\alpha\tau}\,(A_a/A_g)\,F_R\,(\tau\alpha)_{e,\,n}\,G_t M A_g - (A_a/A_g)\,F_R U_L M A_g\,(t_{a,\,l} - t_{a,\,t})}{1 - [(A_a/A_g)\,(F_R U_L M A_g)\,A_g]/[\dot{m}_s\,c_{p,s}]} \qquad \text{........(B.20)}$$

In the most general case of M rows of N collectors connected in series :

$$\dot{Q}_{lh} = \frac{K_{\alpha\tau}\,(A_a/A_g)\,F_R\,(\tau\alpha)_{e,\,n}\,G_t MNA_g - (A_a/A_g)\,(F_R U_L)_N MNA_g\,(t_{a,\,l} - t_{a,\,t})}{1 - [(A_a/A_g)\,(F_R U_L)_N MNA_g)]/(m_s\,c_{p,s})} \qquad \text{........(B.21)}$$

Within the limits of the assumptions made in the above analysis, either configuration using the non-irradiated solar collector array could be used provided the appropriate equations were used to control the collector loop heater [equation (B.15) or (B.21)]. However, locating the collector loop heater downstream of the collector array was chosen due to the simpler expression for $\dot{Q}_{lh}$, equation (B.15).

It should be noted with reference to equation (B.1) and (B.15) that the value of F_R is dependent upon mass flow rate and the specific heat of the transfer fluid. Therefore, if the flow rate of the transfer fluid through the collector in the operation of the solar hot water system is different from the value used during the tests on the collector, then the value of F_R used in equation (B.15) must be modified from that value obtained from the collector tests. This can be done utilizing the following procedure :

1. Calculate $(\tau\alpha)_{e,\,n}$ for the solar collector. For an ordinary flat-plate collector

$$(\tau\alpha)_{e,\,n} = \frac{\tau_n\,\alpha_p}{1 - (1 - \tau_n)\,\rho_d} \qquad \text{........(B.22)}$$

where

ρ_d = 0.16 for a one-cover glass system

= 0.24 for a two-cover glass system

= 0.29 for a three-cover glass system

For concentrating or other types of collectors, the value of $(\tau\alpha)_{e,\,n}$ must be determined based on the geometrical and optical properties of the collector.

2. Calculate the value of F_R from the collector tests by

$$F_R = \frac{Y \text{ intercept of the efficiency curve}}{(A_a/A_g)\,(\tau\alpha)_{e,\,n} \text{ from step 1 above}}$$

3. Calculate the value of the U_L from the collector tests by :

$$U_L = \frac{\dfrac{A_a}{A_g} F_R U_L}{\dfrac{A_a}{A_g} F_R}$$

where $(A_a/A_g) F_R U_L$ is the absolute value of the slope of the efficiency curve at a value of $(t_{set} - t_{a,t})/G_t$ at solar noon during the system test.

4. Calculate the collector efficiency factor, F' by

$$F' = \frac{\dot{m}_c c_{p,c}}{A_a U_L} \ln \left[1 - \frac{F_R A_a U_L}{\dot{m}_c c_{p,c}} \right] \qquad \text{...... (B. 23)}$$

5. Once F' is determined, F_R can be calculated for any system's transfer fluid flow rate and specific heat by using:

$$F_R = \frac{\dot{m}_s c_{p,s}}{M A_a U_L} \left[1 - e^{-\frac{M A_a U_L F'}{\dot{m}_s c_{p,s}}} \right] \qquad \text{...... (B. 24)}$$

It should be noted that the above correction technique is based on the assumption that the collector absorber plate efficiency factor, F', is not a function of flow rate. However, when using air as the transfer fluid the assumption is not valid. The correction technique should not be used under those conditions unless the flow rate per unit collector area of air through the array during the system test differs from that used in the collector tests by less than 25 percent. Otherwise, the collector tests should be repeated with the collector flow rates per unit area existing in the system test used.

ANNEX C

(Normative)

(*Clause* 8.8.1)

SELECTIVE ORDINATE FOR GLOBAL IRRADIANCE

100 selected ordinates for global irradiance. Data given at the wavelengths (λ, μm) midpoints of the equal energy intervals (percent) for air mass 1.5 total hemispherical irradiance (951.53 W/m^2), incident on a 37° tilted surface facing the equator and ground albedo of 0.2

Percent	λ_k	*Percent*	λ_k
0.50	0.3300	50.50	0.7178
1.50	0.3499	51.50	0.7234
2.50	0.3669	52.50	0.7317
3.50	0.3810	53.50	0.7410
4.50	0.3933	54.50	0.7528
5.50	0.4027	55.50	0.7631
6.50	0.4112	56.50	0.7688
7.50	0.4195	57.50	0.7756
8.50	0.4287	58.50	0.7834
9.50	0.4365	59.50	0.7935
10.50	0.4435	60.50	0.8057
11.50	0.4499	61.50	0.8203
12.50	0.4561	62.50	0.8312
13.50	0.4662	63.50	0.8375
14.50	0.4686	64.50	0.8459
15.50	0.4750	65.50	0.8560
16.50	0.4808	66.50	0.8656
17.50	0.4872	67.50	0.8750
18.50	0.4936	68.50	0.8888
19.50	0.4999	69.50	0.9071
20.50	0.5062	70.50	0.9239
21.50	0.5126	71.50	0.9484
22.50	0.5192	72.50	0.9676
23.50	0.5255	73.50	0.9814
24.50	0.5318	74.50	0.9873
25.50	0.5382	75.50	0.9933
26.50	0.5430	76.50	1.0102
27.50	0.5473	77.50	1.0276
28.50	0.5523	78.50	1.0445
29.50	0.5589	79.50	1.0599
30.50	0.5655	80.50	1.0800
31.50	0.5722	81.50	1.1288
32.50	0.5793	82.50	1.1616
33.50	0.5863	83.50	1.1820
34.50	0.5932	84.50	1.1990
35.50	0.5998	85.50	1.2150
36.50	0.6065	86.50	1.2310
37.50	0.6132	87.50	1.2582
38.50	0.6201	88.50	1.2891
39.50	0.6270	89.50	1.4150
40.50	0.6340	90.50	1.5023
41.50	0.6409	91.50	1.5404
42.50	0.6478	92.50	1.5788
43.50	0.6549	93.50	1.6206
44.50	0.6620	94.50	1.6527
45.50	0.6691	95.50	1.6879
46.50	0.6776	96.50	1.7747
47.50	0.6863	97.50	2.0704
48.50	0.6962	98.50	2.1791
49.50	0.7069	99.50	2.3111

ANNEX D

(Normative)

(*Clause* 8.8.1)

CALCULATION OF SPECTRUM WEIGHTED VALUES OF OPTICAL PROPERTIES

The spectrum-weighted value of an optical property P can be computed as:

$$P = \frac{\sum_{i=1}^{n} P(\lambda_i)\, E_{\lambda i}\, \Delta\lambda_i}{\sum_{i=1}^{n} E_{\lambda i}\, \Delta\lambda_i}$$

where $E_{\lambda i}$ is the spectral irradiance at the wavelength λ_i, $\Delta\lambda_i$ is the wavelength interval, $P(\lambda_i)$ is the average value of the optical property in the wavelength interval, and n is the number of wavelengths for which each E_λ is known. The wavelength intervals are given by :

$$\Delta\lambda_i = \frac{\lambda_{i+1} - \lambda_{i-1}}{2}$$

except for the first and last interval, which are given by :

$$\Delta\lambda_1 = \lambda_2 - \lambda_1$$

and

$$\Delta\lambda_n = \lambda_n - \lambda_{n-1}$$

Values of λ_i and $E\lambda_i$ for the standard air mass 1.5 solar spectrum are tabulated in Annex C. Values of E for the simulator shall be measured in accordance with **8.8.1**.

This spectrum weighting procedure shall be applied to the relevant product of spectral optical properties (for example, $\tau\alpha$, $\rho\tau\alpha$)

ANNEX E

(Normative)

(*Clause* 9)

THE CALCULATION OF EQUIVALENT IRRADIANCE

During thermal performance testing of SDHW systems, the effects of diffuse irradiance and the incident angle of beam irradiance occuring throughout the day should be accounted for. Table 5 of Annex A gives values of diffuse and beam incident solar radiation to be applied to the solar collector array and the corresponding incident angles for beam irradiance. When testing with a solar simulator, it is often not practical or possible to produce these conditions by varying the simulator lamp-to-collector orientation or the level of diffuse radiation in the simulator enclosure. In these cases or when using a thermal simulator, it is necessary to use.an "equivalent irradiance". This is the power level (in the case of a thermal simulator) or radiation level that, when applied normal to the plane of the collector by a solar irradiance simulator, represents the irradiance that would have resulted had the conditions listed in Table 5 (Annex A) actually occurred, including the effects of direct and diffuse irrandiance and incident angle.

The thermal performance of an irradiated solar collector operating under quasi-steady-state conditions can be described as given in Annex B as :

$$\frac{\dot{Q}_u}{A_a} = K_{\alpha\tau} F_R (\tau\alpha)_{e,n} G_t - F_R U_L (t_{f,i} - t_a) \qquad \text{..........(E.1)}$$

or letting $t_{f,m} = (t_{f,i} - t_{f,e})/2$ ....(E.2)

$$\frac{\dot{Q}_u}{A_a} = K_{\alpha\tau} F' (\tau\alpha)_{e,n} G_t - F' U_L (t_{f,m} - t_a) \qquad \text{..........(E.3)}$$

In both cases the value of $K_{\alpha\tau} . G_t$ can be as :

$$K_{\alpha\tau} . G_t = (K_{\alpha\tau} . G_{bp} + K_d . G_d) \qquad \text{..........(E.4)}$$

or for a particular incident angle θ,

$$K_{\alpha\tau}(\theta) . G_t = [K_{\alpha\tau}(\theta) . G_{bp} + K_d . G_d] \qquad \text{..........(E.5)}$$

where, $K_{\alpha\tau}(\theta)$ is the value of the incident angle modifier at an angle θ to a normal to the collector aperture plane, and G_{bp} and G_d are values of direct beam and diffuse solar irradiance incident on the apperture plane of the collector.

For most cases, values of K_d may be estimated from :

$$K_d = \int_{\theta=0}^{90^\circ} [K_{\alpha\tau}(\theta) . \sin(2\theta)]\, d\theta \qquad \text{..........(E.6)}$$

For collectors with essentially planar glazings and absorber surfaces; the value of K_d can be approximated by the value of $K_{\alpha\tau}$ (60°), that is:

$$K_d = K_{\alpha\tau} (60^\circ) \qquad \text{..........(E.7)}$$

For systems that use collectors in which the value of $K_{\alpha\tau}$ is not symmetrical, K_d may vary depending on which axis it is evaluated in (for example, horizontal versus vertical incidence angles); it may be necessary to complete a more complex calculation of K_d. These effects may be most significant for collectors employing tubular collectors or collectors employing trough structures, mirrors, or lenses such that the geometries are characterized by biaxial symmetery.

To estimate the "equivalent irradiance" it is necessary to know the variation of incidence angle modifier, $K_{\alpha\tau}$, with respect to the incident angle of beam irradiance, θ, for the solar collector array used in the SDHW system under evaluation. Using these values, the "equivalent irradiance" may be calculated as described below, for each of the following cases.

Testing with a solar simulator

When a solar irradiance simulator is used and the lamp-to-collector orientation is adjusted to a value θ_m but the irradiance is effectively all direct beam radiation, the effects of diffuse irradiance as specified in Table 5 should be accounted for. In this case the "equivalent irradiance", G_{eq}, (measured in the aperture plane of the collector) is given from:

$$G_{eq} \cdot K_{\alpha\tau}(\theta_m) = [G_{bp} \cdot K_{\alpha\tau}(\theta) + G_d \cdot K_d] \qquad \text{..........(E.8)}$$

or $$G_{eq} = [G_{bp} \cdot K_{\alpha\tau}(\theta) + G_d K_d]/K_{\alpha\tau}(\theta_m) \qquad \text{..........(E.9)}$$

The "equivalent irradiance" can be related to the direct normal irradiance measured in a plane perpendicular to the direction of beam irradiance coming from the solar simulator, $G_{DN,m}$, according to :

$$G_{eq} = G_{DN,m} \cdot \cos(\theta_m) \qquad \text{........(E.10)}$$

For the case in which the lamp-to-collector orientation is adjusted each hour of the test such that; $\theta_m = \theta$; where θ represents the values given in Table 5 corresponding to the test hour, then;

$$G_{eq} = G_{bp} + [G_d \cdot K_d/K_{\alpha\tau}(\theta)] \qquad \text{........(E.11)}$$

where G_{dp} and G_d are specified in Table 5 for the corresponding value of θ during the test hour of the test day.

For the case in which the lamp-to-collector orientation is fixed such that the radiation coming from the solar simulator is directly normal to the aperture plane of the solar collector such that $\theta_m = 0°$, then;

$$G_{eq} = [G_{bp} \cdot K_{\alpha\tau}(\theta) + G_d \cdot K_d]/K_{\alpha\tau}(0°) \qquad \text{........(E.12)}$$

which equals,

$$G_{eq} = [G_{bp} \cdot K_{\alpha\tau}(\theta) + G_d \cdot K_d] \qquad \text{........(E.13)}$$

since by definition, $K_{\alpha\tau}(0°) = 1$.

Testing with a thermal simulator :

When testing with a thermal simulator, the power output of the heater should be determined by the method described in Annex B, accounting for the effects of diffuse irradiance and the incident angle of beam irradiance as specified in Table 5. In this case the vlaue of $K_{\alpha\tau} \cdot G_t$ used in the calculation of the thermal simulator output (Annex B) should be given by:

$$K_{\alpha\tau} \cdot G_t = [K_{\alpha\tau}(\theta) \cdot G_{bp} + K_d \cdot G_d] \qquad \text{........(E.14)}$$

where the values of θ, G_{bp}, and G_d are the values given in Table 5 corresponding to the hour of the test day.

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